

collision to collision would be inversely as the average velocity of the particles. But Maxwell's experiments on the variation of the viscosities of gases with change of temperature prove that the mean time from collision to collision is independent of the velocity, if we give the name collision to those mutual actions only which produce something more than a certain specified degree of deflection of the line of motion. This law could be fulfilled by soft elastic particles (globular or not globular); but, as we have seen, not by hard elastic globes. Such details, however, are beyond the scope of our present argument. What we want now is rough approximations to absolute values, whether of time or space or mass—not delicate differential results. By Joule, Maxwell, and Clausius we know that the average velocity of the molecules of oxygen or nitrogen or common air, at ordinary atmospheric temperature and pressure, is about 50,000 centimetres per second, and the average time from collision to collision a five-thousand-millionth of a second. Hence the average length of path of each molecule between collisions is about $\frac{1}{100000}$ of a centimetre. Now, having left the idea of hard globes, according to which the dimensions of a molecule and the distinction between collision and no collision are perfectly sharp, something of apparent circumlocution must take the place of these simple terms.

First, it is to be remarked that two molecules in collision will exercise a mutual repulsion in virtue of which the distance between their centres, after being diminished to a minimum, will begin to increase as the molecules leave one another. This minimum distance would be equal to the sum of the radii, if the molecules were infinitely hard elastic spheres; but in reality we must suppose it to be very different in different collisions. Considering only the case of equal molecules, we might, then, define the radius of a molecule as half the average shortest distance reached in a vast number of collisions. The definition I adopt for the present is not precisely this, but is chosen so as to make as simple as possible the statement I have to make of a combination of the results of Clausius and Maxwell. Having defined the radius of a gaseous molecule, I call the double of the radius the diameter; and the volume of a globe of the same radius or diameter I call the volume of the molecule.

The experiments of Cagniard de la Tour, Faraday, Regnault, and Andrews, on the condensation of gases do not allow us to believe that any of the ordinary gases could be made forty thousand times denser than at ordinary atmospheric pressure and temperature, without reducing the whole volume to something less than the sum of the volume of the gaseous molecules, as now defined. Hence, according to the grand theorem of Clausius quoted above, the average length of path from collision to collision cannot be more than five thousand times the diameter of the gaseous molecule; and the number of molecules in unit of volume cannot exceed 25,000,000 divided by the volume of a globe whose radius is that average length of path. Taking now the preceding estimate, $\frac{1}{100000}$ of a centimetre, for the average length of path from collision to collision, we conclude that the diameter of the gaseous molecule cannot be less than $\frac{1}{500000000}$ of a centimetre; nor the number of molecules in a cubic centimetre of the gas (at ordinary density)

greater than 6×10^{24} (or six thousand million million million).

The densities of known liquids and solids are from five hundred to sixteen thousand times that of atmospheric air at ordinary pressure and temperature; and, therefore, the number of molecules in a cubic centimetre may be from 3×10^{24} to 10^{26} (that is, from three million million million million to a hundred million million million million). From this (if we assume for a moment a cubic arrangement of molecules), the distance from centre to nearest centre in solids and liquids may be estimated at from $\frac{1}{140000000}$ to $\frac{1}{400000000}$ of a centimetre.

The four lines of argument which I have now indicated, lead all to substantially the same estimate of the dimensions of molecular structure. Jointly they establish with what we cannot but regard as a very high degree of probability the conclusion that, in any ordinary liquid, transparent solid, or seemingly opaque solid, the mean distance between the centres of contiguous molecules is less than the hundred-millionth, and greater than the two thousand-millionth of a centimetre.

To form some conception of the degree of coarse-grainedness indicated by this conclusion, imagine a rain drop, or a globe of glass as large as a pea, to be magnified up to the size of the earth, each constituent molecule being magnified in the same proportion. The magnified structure would be coarser grained than a heap of small shot, but probably less coarse grained than a heap of cricket-balls.

W. T.

FRESENIUS'S ANALYSIS

Qualitative Chemical Analysis. By Dr. C. Remigius Fresenius. Seventh Edition. Edited by Arthur Vacher. 8vo., pp. viii. and 264. (London: Churchill, 1869.)

Quantitative Chemical Analysis. By Dr. C. Remigius Fresenius. Fifth edition. Edited by Arthur Vacher. 8vo., pp. viii. and 377. (London: Churchill, 1870.)

Anleitung zur qualitativen chemischen Analyse. By Dr. C. Remigius Fresenius. 8vo., pp. xii. and 240, with 43 woodcuts; price 4s. (Brunswick, 1869. London: Williams and Norgate.)

In no branch of chemistry, perhaps, has more useful progress been made of late years than in analysis. The other departments of the science, technical and organic chemistry, for instance, have been cultivated with assiduity and even ostentation; while the study of analysis, invaluable and necessary as it is, has been comparatively neglected as humble and unadorned. Much of this apathy has no doubt arisen from the mechanical nature of the task of analytical discovery, which commonly requires a greater share of industry than intellectual effort. The gradual introduction of refined physical methods has, however, commenced, and will no doubt complete an entire change in the aspect of this subject.

Chemists will not need to be reminded of the obligations they owe to Fresenius, whose analytical manuals are deservedly known, and in common use in almost every laboratory. The enormous amount of special results they contain is hardly conceivable to an outsider, who will not readily appreciate the respect paid to them by grateful

practitioners. The thirteenth edition (of which the first instalment has just reached us) has been retouched and improved, and is in every way worthy of the confidence of chemists. Its appearance has, however, suggested to us some reflections which might, not improbably, be carried out with advantage. Few readers will fail to observe that the dimensions of the book and the subject have both increased, and at a rate that will necessitate a remedy in the course of a few years. Possibly it may be agreed that, in addressing a single book to four kinds of students, the author has performed a somewhat superfluous task for three of them. Those who are engaged in pharmacy, the arts, manufactures, and agriculture, will all find here much more than they respectively require. The inconvenience obviously admits of easy removal; each class ought to have a handbook suited to its own peculiar demands, and to those alone. The mere economy of time thus effected would be an additional recommendation to such a step. Moreover, it would allow of altering, for the sake of the purely chemical student, the entire system of nomenclature and notation. These admittedly belong to a period that has passed away; and their presence in the book universally interferes much with its proper utility in the laboratory. The apology in the preface will hardly be accepted by teachers; neither can we suppose that the author, if writing specially, would say of chemistry that it is "the science which acquaints us with the substances of which our earth consists, their composition and decomposition, and mutual deportment generally." It is time that this barren and lifeless definition ceased to be adopted by every instructor. There is, indeed, a quaint mediæval tone about the whole of the book.

The historical reader will notice under the section devoted to "Operations," titles and processes and explanations that abound as we trace our steps backwards from Thénard. The practical investigator might regret the omission of Bunsen's method of filtration, of argentic sulphate as a common impurity in the nitrate, of the formation of Claudet's body as a test for cobalt. We see a condenser figured which could not easily be used with a continuous stream of water, and has been long abandoned in laboratories. Again, hydric nitrate is said to be purified by distilling at the temperature of ebullition; which does not, however, occur unless under that point. We may, nevertheless, assure the experimenter that he will not find in Dr. Fresenius's work more than a few errors of the kind which affect him. There is evidence throughout it of accumulated care and forethought, and the writer's clear exposition and systematic procedure are a proof both of unsparing labour and severe economy.

The author's two German treatises have hitherto been presented to the English student in the form of translations, which portrayed the characteristic features of the originals with satisfactory fidelity. But, for the reasons we have already intimated, there has been a general desire for such changes as would make each of these volumes a handy laboratory book. Mr. Vacher has boldly taken upon himself this task of dual reform, having "specially striven to meet the present wants of English students." He has no doubt succeeded in making two thoroughly English books, which will be most valuable to students;

but they can no longer be legitimately termed editions of Fresenius, which they resemble only as a pen-and-ink sketch resembles a perfect picture. That the editor himself is to a certain extent conscious of this is tolerably apparent from the following passages, which are too important to be left unnoticed:—"The present edition has been entirely re-written and much condensed. . . . The metals have been grouped anew, and the old grouping of the acids has been abandoned. . . . The processes have been made as far as possible complete in themselves, so as to obviate constant reference to different pages of the book. Several new figures have been added, and the number of tables has been increased. I have endeavoured to render the arrangement as simple as possible" (preface to "Quantitative Analysis"). And again, "The language has been condensed, the notation and nomenclature have been modernised, the arrangement has been simplified. The consideration of rare inorganic bodies and of organic has been deferred to the latter part of the volume, where a section has been devoted to each. . . . The cause of analysis has been simplified in description, and the preliminary examination has been curtailed. . . . All the facts and, except in one or two trivial instances, all the processes given in this edition have the authority of Fresenius, but the principal changes in the arrangement have been made on my own responsibility" (preface to the "Qualitative Analysis"). Editions for which the editor is thus far responsible, while the reputed author is responsible for a part only of the *facts* (not the whole of them, as Mr. Vacher states), ought not to bear Fresenius's name in any other than a subordinate manner, all these works are, in reality, outlines of analytical chemistry on the basis of Fresenius.

Mr. Vacher has, on the whole, however, carried out successfully the various changes he had in view. The adoption of the prevailing notation is in itself an improvement, teachers having hitherto been compelled to use one interpretation for symbols in the lecture-room, and another in the laboratory. He has not, however, quite so well fulfilled his promise as to the nomenclature, which is still unsystematic, and therefore misleading. For example, at p. 3 ("Quantitative Analysis") we find *calcium chloride*, at p. 27 *carbonate of calcium*; at p. 40 *ferrous sulphide*, at p. 42 *sulphide of manganese*, at p. 40 *ferric oxide*, at p. 44 *alumina*. At p. 54 the word "acid" undergoes a very sudden transformation; "Ignited titanous acid does not dissolve in hydrochloric acid." These instances of haste, of which there are not a few, ought to be removed from the next edition.

It seems hardly probable that these large analytical treatises will be perfectly available for the use of students until they are divided into separate works. Subjects such as water analysis, manure analysis, volumetric analysis, assaying, &c., require, as we have said, a separate treatment. Mere condensation, however ably performed, will not accomplish a widely useful end. Mr. Vacher, nevertheless, deserves much credit for a hazardous experiment, which, though not altogether unimpeachable, is a real service to chemistry.

Our general impression of analysis is, that, both in point of scientific form and literary expression, it needs a strong stimulus from other quarters.